

Research Article

The diversity and conservation status of amphibians and reptiles from the Mexican biogeographic province of Sierra Madre del Sur

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Abstract

The Sierra Madre del Sur (SMS) is a biologically diverse biogeographic province found in south-central Mexico. It is therefore an area of interest from a conservation standpoint. Here we examine the diversity and conservation status of the amphibians and reptiles of the SMS and its subprovinces and determine their similarity with neighboring provinces. We compiled a list of the species of amphibians and reptiles occurring in the SMS and its neighboring provinces from the available literature and gathered information on their conservation status. We also compiled the herpetofauna of the three subprovinces of the SMS (Western, Central, and Eastern). The SMS houses 186 species of amphibians, of which 89% are endemic to Mexico and 53% endemic to the SMS. The SMS also contains 331 reptile species, of which 72% are endemic to Mexico and 23% are endemic to the SMS. The amphibian and reptile diversity of the SMS is concentrated in the Eastern subprovince. The significant number of amphibian and reptile species endemic to the SMS highlights its importance for conservation. Comparison with neighboring provinces shows that the SMS shares 33% of its species with the Transvolcanic Belt, 25% with the Pacific Lowlands and Balsas Basin, and 19% with Veracruz. The SMS shares 52% of its reptile species with the Transvolcanic Belt, 42% with the Pacific Lowlands, 40% with the Balsas Basin, and 33% with the Veracruz. The results of a cluster analyses suggest that the SMS does not represent a single unit in terms of its herpetofauna, since the three subprovinces do not cluster together. The Western and Central subprovinces cluster with the Balsas Basin and the Pacific Lowlands, whereas the Eastern subprovince clusters separately. We found that 25.7% of the evaluated amphibian and reptile species in the SMS are included in the International Union for Conservation of Nature's (IUCN) Red List in some category of conservation concern (amphibians: 54.9%; reptiles: 6.8%). The Eastern subprovince hosts the highest proportion of species of conservation concern (93.8%). It is important to increase the number of areas protected by federal and state governments, especially in the Eastern subprovince, and to promote protections driven by local communities. These actions could help protect the herpetofauna of the SMS, especially the Eastern subprovince, which harbors a unique fauna and deserves special consideration from a conservation standpoint.

Key words: Diversity, endemic species, herpetofauna, Mexico, species richness

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Introduction

The Sierra Madre del Sur (SMS) is home to an incredible biodiversity that has attracted the attention of naturalists since the first scientific explorations carried out in Mexico in the 19th Century (Espinosa et al. 2016). Using the National Biodiversity Information System (SNIB) for the SMS polygon, Espinosa et al. (2016) reported the presence of 18 species of arthropods, 35 fish, 116 amphibians, 208 reptiles, 390 birds, 165 mammals, 187 fungi, 150 mosses, liverworts, and hornworts, 350 ferns and others, 49 conifers, cycads, and ephedras, and 6,467 of flowering plants. However, there has been an increase in our understanding of the amphibians and reptiles present in the SMS in recent years. For example, between the years 2016 and 2022, 17 species of amphibians and 11 species of reptiles endemic to this biogeographic province have been described with type localities in the SMS, as well as others that were described in the SMS that are not endemic to it (e.g., anurans: Canseco-Márquez et al. 2017b; Campbell et al. 2018; Grünwald et al. 2018, 2019, 2021a; Kaplan et al. 2020; lizards: Campbell et al. 2016; Köhler et al. 2019; McCranie et al. 2020; García-Vázquez et al. 2021; Nieto-Montes de Oca et al. 2022; snakes: Wallach 2016; García-Vázquez et al. 2018; Mata-Silva et al. 2019; Carbajal-Márquez et al. 2020; Grünwald et al. 2021b). In addition, several studies reporting lists of amphibians and reptiles from the states included in the SMS have been published that expand and solidify our knowledge of the amphibians and reptiles of the states that contain the SMS (Jalisco: Cruz-Sáenz et al. 2017; Colima: Lemos-Espinal et al. 2020; Reyes-Velasco et al. 2020a; Michoacán: Alvarado-Díaz et al. 2013; Guerrero: Palacios-Aguilar and Flores-Villela 2018; Oaxaca: Mata-Silva et al. 2021; Puebla: Woolrich-Piña et al. 2017).

The compilation of such species lists and their conservation status, as well as comparisons among neighboring biogeographic provinces are useful in creating a baseline understanding of the diversity of the region, as well as highlighting particularly important biogeographic provinces or regions in need of conservation efforts. In particular, comparing the herpetofaunas of neighboring provinces and determining their similarity can provide further insights into whether larger scale conservation planning is needed (e.g., across provinces) or whether conservation planning at the biogeographic province is more appropriate. Such an approach has been applied at the state level, establishing similarities in herpetofaunas among biogeographic provinces and their relative conservation priority as a means to target potential conservation and management efforts within those states (e.g., Woolrich-Piña et al. 2017; Ramírez-Bautista et al. 2020; Cruz-Elizalde et al. 2022; Leyte-Manrique et al. 2022; Calderón-Patrón et al. 2024). Since the biogeographic provinces presumably reflect biologically relevant geographic units (e.g., Morrone 2017, 2019), they may be a more appropriate level of investigation than states, which are typically arbitrary, politically determined areas that may or may not be biologically relevant.

In this paper we report the species of amphibians and reptiles that have been recorded in the SMS and its three subprovinces (Western, Central, and Eastern; Morrone 2005, 2017, 2019; Gopar-Merino and Velázquez 2016; Luna-Vega et al. 2016; Morrone et al. 2017; Aragón-Parada et al. 2021) and compare them with the species lists of the four neighboring biogeographic provinces (Veracruz, Transvolcanic Belt, Pacific Lowlands, and Balsas Basin). We are particularly interested in determining how unique the SMS is compared to neighboring

provinces and establish how important it is from a conservation perspective to the Mexican herpetofauna. To this end, we compiled the conservation status of the amphibians and reptiles of the SMS and its subprovinces, as well as the number of Mexican and province endemics. By examining the species composition of each subprovince we are also able to determine whether the entire SMS province should be treated as a single conservation unit or whether conservation strategies need to be targeted at one or more of the subprovinces.

Methods

Physiographic characteristics

The Sierra Madre del Sur (SMS) is located in south-central Mexico, covering an area of 93,607 km² extending from 15.8423° and 21.0125° latitude and -95.0822° and -105.4579° longitude, with a perimeter of 9,223 km. The SMS is bordered by the Pacific Lowlands to the west and south (border length = 4,149 km), to the east by the Veracruzán (border length = 677 km), and to the north by the Balsas Basin (border length = 3,964 km) and the Transvolcanic Belt (border length = 434 km). It is a mountain range that runs parallel to the Pacific Lowlands in a northwest to southeast direction, from Cabo Corrientes in western Jalisco, to the Isthmus of Tehuantepec in southern Oaxaca; from there it extends north through eastern Oaxaca to southern Puebla. It occupies parts of the states of Jalisco, Colima, Michoacán, Guerrero, Oaxaca, and Puebla (Fig. 1). It is divided into three subprovinces: Western, which includes the districts of Jalisco and Jalisco-Manantlán, with elevations ranging from 300 to 2,890 m asl; Central that corresponds to the Michoacán district with elevations ranging from 300 to 2,890 m asl; and Eastern, which includes the Guerrero and Oaxaca districts, with elevations ranging from 200 to 3,730 m asl (Morrone 2017, 2019). The physiographic characteristics of each of the three subprovinces are different. The Western subprovince represents the northern and western limits of the SMS, and covers an area of 11,267 km² that represents 12.0% of the SMS. The Central subprovince covers an area of 9,008 km² that represents 9.6% of the SMS. The Eastern subprovince on its southwest and south sides bordering the Pacific Lowlands represents the southern and eastern limits of the SMS, and covers an area of 73,331 km² that represents more than 78.0% of the total area of the SMS, and it is more than 6.5 and 8.0 times larger than the Western and Central subprovinces, respectively.

The vegetation type includes coniferous and oak forest (47%), tropical deciduous forest (24%), mountain cloud forest (15%) and evergreen tropical forest, subdeciduous tropical forest, scrubland, xeric, grassland and other types of vegetation together (14%; Rzedowski 1978; Aragón-Parada et al. 2021). Although its location is within the tropics, its climate is not completely tropical, since its climate includes rainy and warm climate in the eastern portion of the SMS to dry and cold in the highest mountains (Aragón-Parada et al. 2021).

Data collection

Using the available literature, we collected species lists for amphibians and reptiles for all of the Mexican states included in the Sierra Madre del Sur (SMS) biogeographic province, that we updated using additional literature (see Appendix 1).

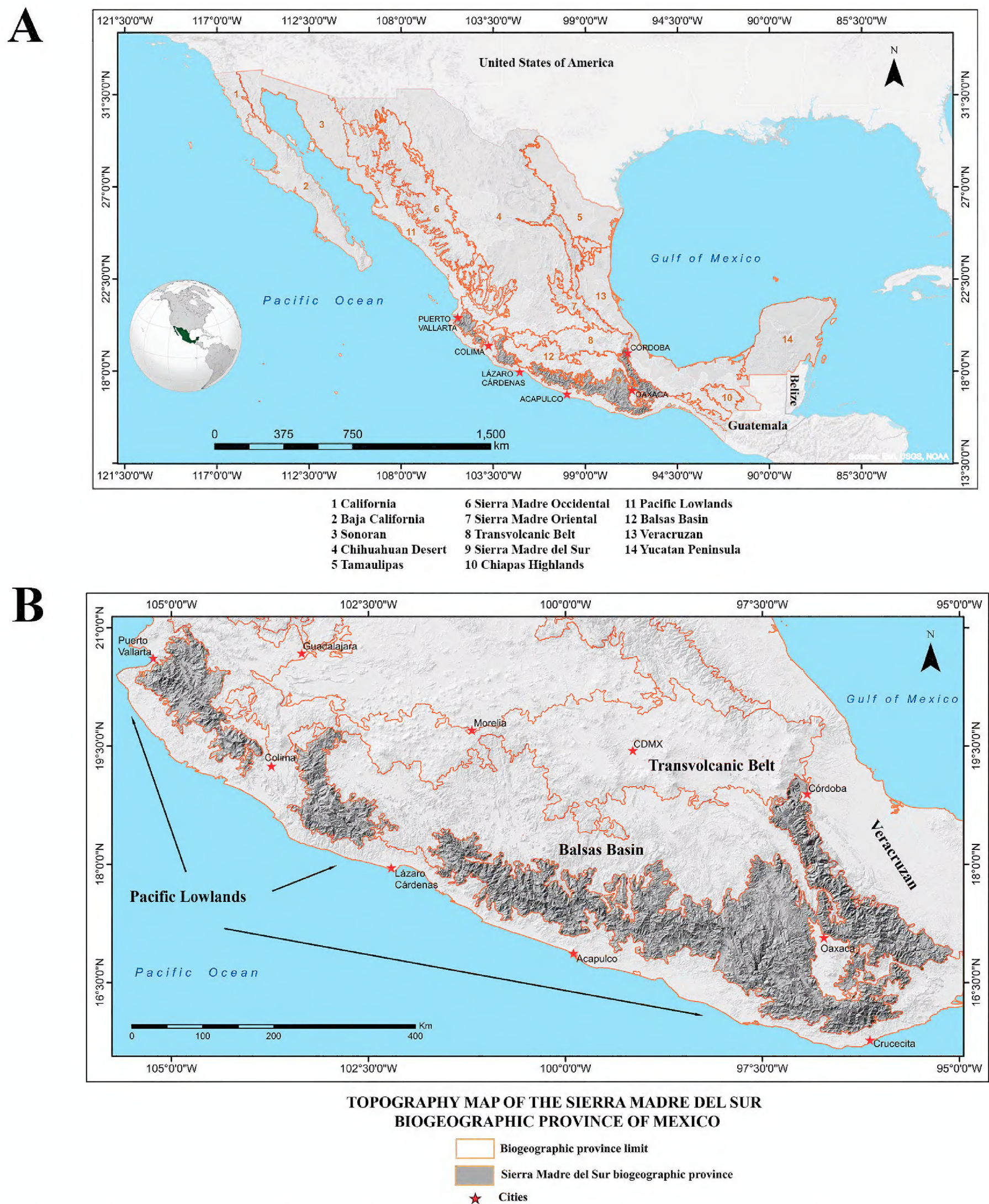


Figure 1. Topographic map of the Sierra Madre del Sur **A** overview of the fourteen biogeographic provinces of Mexico, highlighting the Sierra Madre del Sur in a darker gray tone. The map also includes the southern United States and northern Central America (Guatemala and Belize) **B** a more detailed map focusing on the Sierra Madre del Sur and surrounding provinces, providing a closer view of the region's topography and neighboring areas. (Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model Version 2, 2011).

We initially used databases (e.g., BIOSIS, Zoological Record) to search for literature related to the herpetofauna of the SMS as well as the Mexican states that contain parts of the SMS. We supplemented these searches by examining the reference sections of the literature found via the databased searches. Thus,

most of the literature was from indexed journals. We confirmed records using VertNet, GBIF, and other sources. We encountered no inconsistencies between these other sources and the data reported in the published state lists, which were compiled by experts in those regions and peer-reviewed. In addition, the published state lists used VertNet, GBIF, museum records, literature reviews, and fieldwork. We follow Frost (2024) or AmphibiaWeb (2024) for amphibian names. We chose to reference both sources to ensure a comprehensive approach to taxonomy. While we primarily followed Frost (2024), we used AmphibiaWeb (2024) in some cases where naming conventions diverge (e.g., Frost [2024] uses *Lithobates* and we use *Rana* following AmphibiaWeb (2024) based on established usage in the literature and for consistency with historical naming conventions). We used Uetz et al. (2023) for reptile names. We used the delimitation of the SMS biogeographic province defined by Morrone (2005, 2006, 2017, 2019), and Morrone et al. (2017) to then refine the state checklists to create a species list for SMS and its three subprovinces (Western, Central, and Eastern), as well as the neighboring provinces (Suppl. material 1). We used a similar literature searching process to develop species lists for the neighboring biogeographic provinces (Lemos-Espinal and Smith 2024b): Transvolcanic Belt (Lemos-Espinal and Smith 2024a), Pacific Lowlands (Lemos-Espinal and Smith 2024c), Balsas Basin (Lemos-Espinal and Smith 2025), and Veracruz. In addition, we recorded the conservation status and population trends of each species based on the IUCN Red List 2024-2 (IUCN 2024), Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT) (2019), and Environmental Vulnerability Scores (EVS) from Wilson et al. (2013a, 2013b).

Statistical analyses

We used hierarchical clustering analyses based on Jaccard's Similarity Coefficients for Binary Data as the distance metric and using the single linkages method (nearest neighbor) to generate trees of the three subprovinces of the SMS and the neighboring biogeographic provinces (SMS, Veracruz, Transvolcanic Belt, Pacific Lowlands, and Balsas Basin) for amphibians and reptiles separately. Cluster analyses were performed using Systat 13.2 (Systat Software Inc., San Jose, CA).

Results and discussion

Species richness

Amphibian diversity of the Sierra Madre del Sur (SMS) consists of three orders, 13 families, 34 genera, and 186 species: 131 anurans, 54 salamanders, and one caecilian (Suppl. material 1). One hundred and fifty-seven are endemic to Mexico, and, of these, 98 are endemic to the SMS: 50 anurans and 48 salamanders. This extraordinary number of amphibian species endemic to the SMS, especially to the Eastern subprovince, was previously reported by Montiel-Canales and Goyenechea Mayer Goyenechea (2022), and coincides with a high number of endemic species of lizards (Montiel-Canales et al. 2019), and mammals (Vázquez et al. 2009; Morales et al. 2016). The families with the highest species richness are Hylidae with 64 species (31 endemic to the SMS) and Plethodontidae with

53 (48 endemic to the SMS) (Suppl. material 1). According to the total amphibian diversity of Mexico reported by Ramírez Bautista et al. (2023) or by Lemos-Espinal and Smith (2024b), the SMS is home to 43.3% (186/430) or 42.8% (186/435) of the country's amphibian species, respectively. The reptile diversity of the SMS consists of two orders, two suborders, 25 families, 89 genera, and 331 species: 149 lizards, 174 snakes, and eight turtles (Suppl. material 1). Two hundred and thirty-eight are endemic to Mexico, and, of these, 76 are endemic to the SMS: 41 lizards and 35 snakes (Suppl. material 1). The SMS is home to 33.9% (331/975) or 34.3% (331/964) of the country's total reptile species as determined by Ramírez-Bautista et al. (2023) or Lemos-Espinal and Smith (2024b), respectively. Additionally, at least four species of amphibians and reptiles have been introduced to the SMS: the Common Bullfrog (*Rana catesbeiana*); the Stump-toed Gecko (*Gehyra mutilata*); the Common House Gecko (*Hemidactylus frenatus*); and the Brahminy Blindsnake (*Indotyphlops braminus*).

The greatest diversity of amphibians in the SMS is concentrated in the Eastern subprovince with 168 species that represents 90.3% (168/186) of the total amphibians that inhabit the SMS: 114 anurans, 53 salamanders, and one caecilian (Suppl. material 1). This is followed by the Western subprovince with 30 species: 28 anurans, one salamander, and one caecilian (Suppl. material 1). Finally, the Central province has 27 species, all of them anurans (Suppl. material 1). Likewise, the greatest richness of reptiles is found in the Eastern subprovince with 290 species that represent 87.6% (290/331) of the total reptile species that inhabit the SMS: 130 lizards, 153 snakes, and seven turtles (Suppl. material 1). This is followed by the Western subprovince with 79 species: 26 lizards, 51 snakes, and two turtles; and the Central subprovince with 76 species: 34 lizards, 40 snakes, and two turtles (Suppl. material 1).

The SMS thus has a high diversity of amphibians and reptiles, and represents a key province in Mexico with regard to the country's herpetofauna. In particular, the SMS houses a great number of Mexican endemics, as well as species that are endemic to the SMS (Fig. 2). Indeed, Johnson et al. (2017) identified the SMS as one of five major areas of endemism for the amphibians and reptiles of Mexico (see also Montiel-Canales et al. 2019; Montiel Canales and Goyenechea Mayer Goyenechea 2022 for specific taxa) (Figs 3, 4). Taken together, these observations suggest the SMS should be a critical conservation priority for amphibians and reptiles in Mexico. The Eastern subprovince is especially important.

Comparison with neighboring provinces

The Sierra Madre del Sur (SMS) shares 45% of its amphibian and reptile species with the Transvolcanic Belt (231 shared species), 36% with the Pacific Lowlands (186 shared species), 35% with the Balsas Basin (180 shared species), and 28.2% with the Veracruzian (146 shared species) (Table 1, Suppl. material 2). In addition, it is home to 54.7% of the regional pool (517 of 945 species) (Table 1, Suppl. material 2). For amphibians, the SMS shares 33% (61 species) with the Transvolcanic Belt, 25% (47 species) with the Pacific Lowlands and Balsas Basin, and 19% (36 species) with Veracruzian. Moreover, the SMS contributes significantly to the regional amphibian pool, with 56% (186 out of 332 species). Compared to other biogeographic provinces, the SMS has a unique composition of amphibian species in Mexico. It does not share a high proportion of

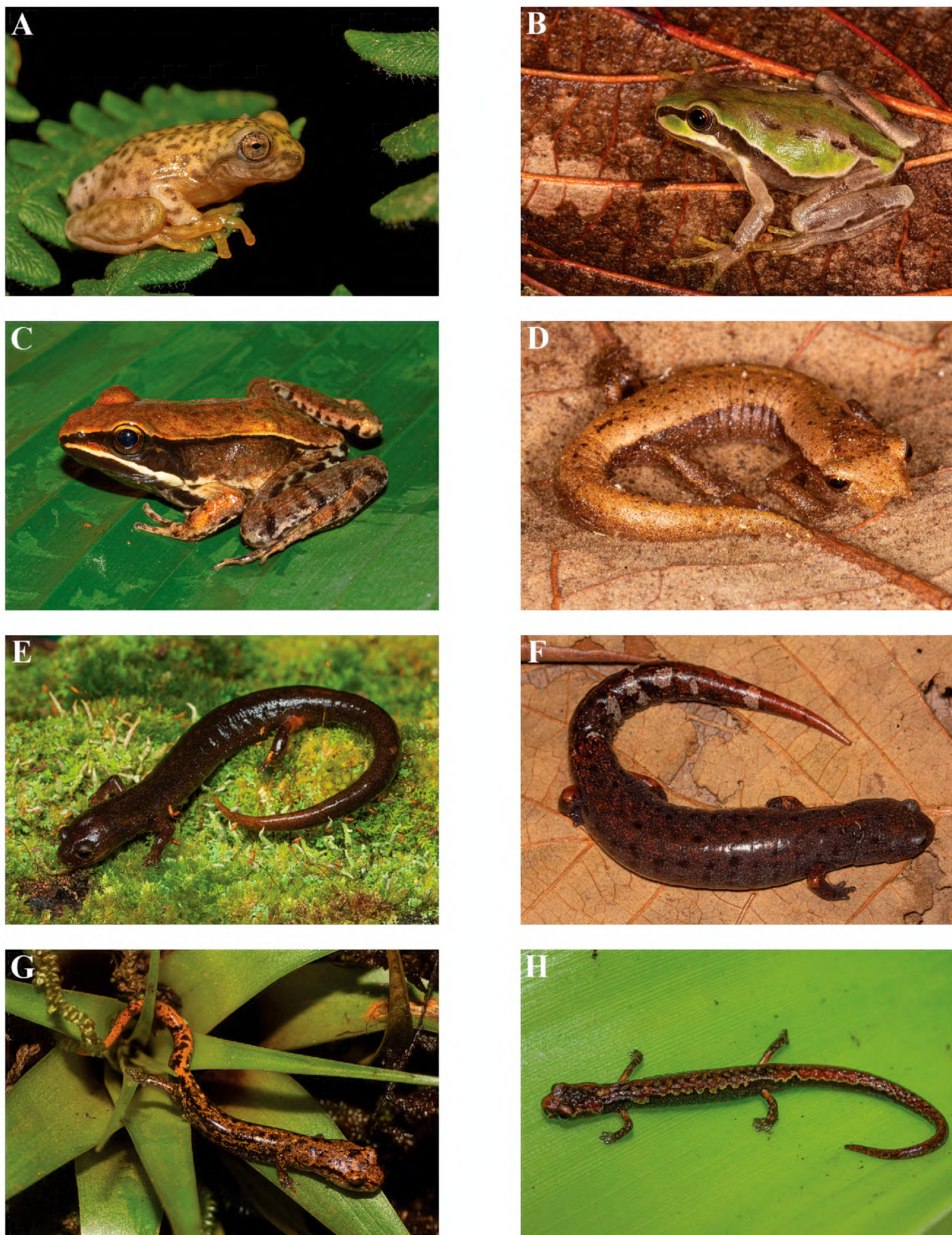


Figure 2. Photos of some of the amphibian species endemic to the Sierra Madre del Sur **A** *Charadrahyla pinorum*, Agua de Obispo, Guerrero **B** *Dryophytes arboricola*, Metlatonoc, Guerrero **C** *Rana sierramadrensis* juvenile, Malinaltepec, Guerrero **D** *Bolitoglossa chinanteca*, San Juan Tabaa, Oaxaca **E** *Pseudoeurycea amuzga*, Malinaltepec, Guerrero **F** *Pseudoeurycea obesa*, San Juan Tabaa, Oaxaca **G** *Pseudoeurycea ruficauda*, Sierra Mazateca, Oaxaca **H** *Thorius adelos*, Sierra Mazateca, Oaxaca. All photos by Eric Centenero-Alcalá.

its amphibian species with neighboring provinces (Table 1, Suppl. material 2) and contributes significantly to the regional species pool because of the high number of amphibian species endemic to the SMS, especially salamanders in the family Plethodontidae (see above). Interestingly, for amphibians the three

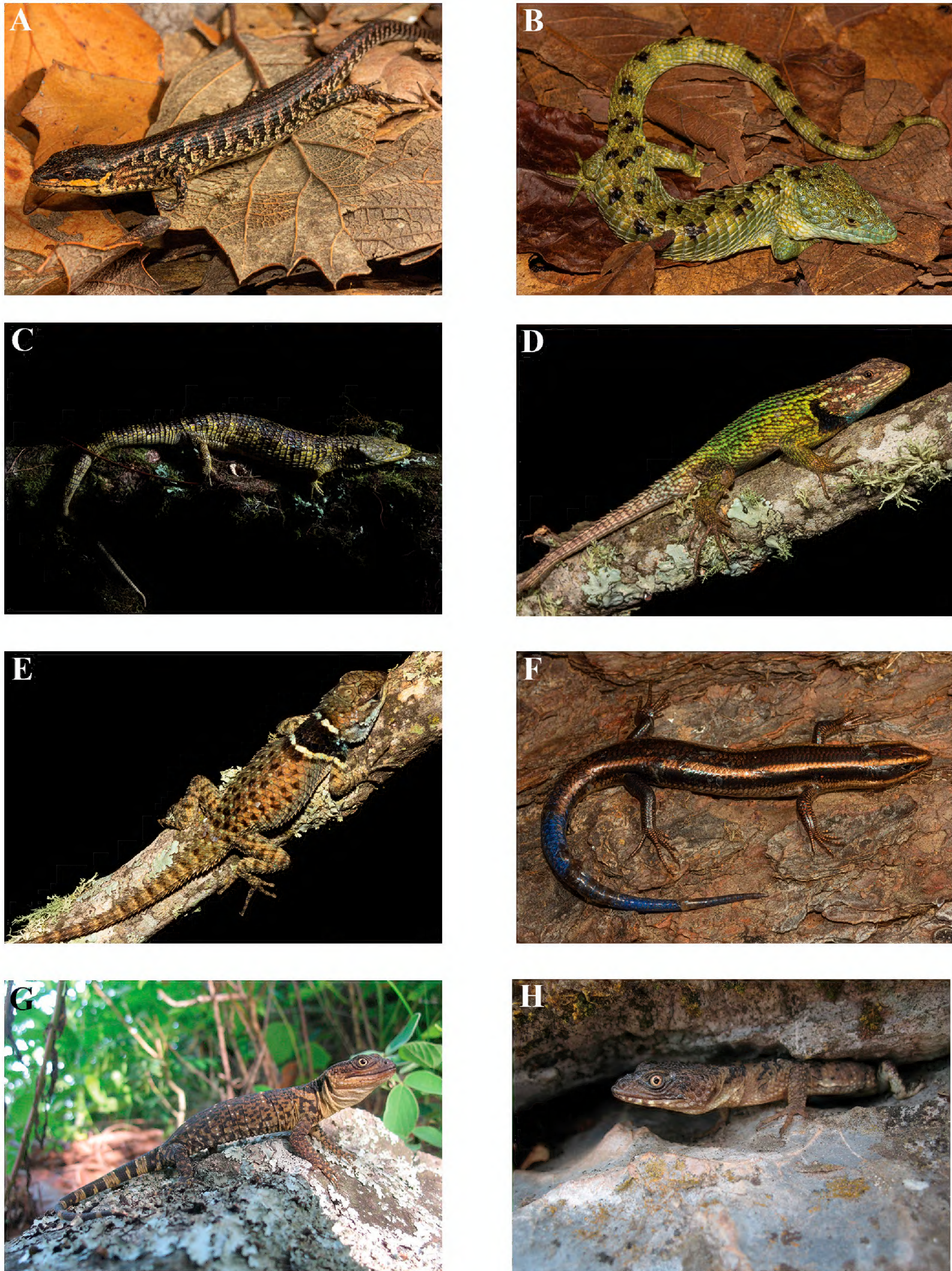


Figure 3. Photos of some of the lizard species endemic to the Sierra Madre del Sur **A** *Abronia gadovii*, Malinaltepec, Guerrero **B** *Abronia mixteca*, Oaxaca **C** *Abronia oaxacae*, San Juan Tabaa, Oaxaca **D** *Sceloporus scitulus*, Malinaltepec, Guerrero **E** *Sceloporus omiltemanus*, Malinaltepec, Guerrero **F** *Plestiodon longiartus*, Malinaltepec, Guerrero **G** *Xenosaurus agrenon*, Cafetal Costa Rica, Oaxaca **H** *Xenosaurus phalaroanthereon*, Santa María Ecatepec, Oaxaca. Photos **A–F** by Eric Centenero-Alcalá; Photos **G** and **H** by Susy Sanoja-Sarabia.

subprovinces of the SMS did not group together (Fig. 5A). The Western and Central subprovinces of the SMS grouped with the Balsas Basin and the Pacific Lowlands. The Veracruz and Transvolcanic Belt grouped together. These two groups were joined together and the Eastern subprovince of the SMS was outside the rest of the provinces.

Table 1. Summary of the number of species shared between the Sierra Madre del Sur (SMS) and neighboring biogeographic provinces (not including introduced species). The percent of the SMS shared by neighboring provinces are given in parentheses. Total refers to the number of species found in the SMS and four neighboring provinces (i.e., regional species pool) and the number in parentheses in this column is the percent of the regional species pool found in the SMS. – indicates either the SMS or their neighboring province has no species in the taxonomic group, or none of that specific taxon is shared between the provinces, thus no value for shared species is provided. Abbreviations of the biogeographic provinces are: SMS (Sierra Madre del Sur); TVB (Transvolcanic Belt); Pacific (Pacific Lowlands).

Biogeographic Province	SMS	TVB	Pacific	Balsas Basin	Veracruz	Total
Class Amphibia						
Order Anura	131	58 (0.44)	45 (0.34)	45 (0.34)	35 (0.27)	210 (0.62)
Bufonidae	11	4 (0.36)	8 (0.73)	6 (0.55)	3 (0.27)	25 (0.44)
Centrolenidae	1	1 (1.0)	1 (1.0)	–	1 (1.0)	1 (100)
Craugastoridae	20	9 (0.45)	7 (0.35)	7 (0.35)	5 (0.25)	31 (0.65)
Eleutherodactylidae	19	7 (0.37)	7 (0.37)	3 (0.16)	3 (0.16)	37 (0.51)
Hylidae	64	24 (0.38)	13 (0.20)	16 (0.25)	16 (0.25)	81 (0.79)
Leptodactylidae	2	2 (1.0)	2 (1.0)	2 (1.0)	2 (1.0)	3 (0.67)
Microhylidae	2	2 (1.0)	2 (1.0)	2 (1.0)	2 (1.0)	5 (0.4)
Ranidae	10	8 (0.8)	4 (0.4)	7 (0.7)	1 (0.01)	24 (0.42)
Rhinophrynidae	1	–	1 (1.0)	1 (1.0)	1 (1.0)	1 (100)
Scaphiopodidae	1	1 (1.0)	–	1 (1.0)	1 (1.0)	2 (50)
Order Caudata	54	2 (0.04)	1 (0.02)	2 (0.04)	1 (0.02)	119 (0.45)
Ambystomatidae	1	1 (100)	–	1 (100)	–	13 (0.08)
Plethodontidae	53	1 (0.02)	1 (0.02)	1 (0.02)	1 (0.02)	104 (0.51)
Salamandridae	–	–	–	–	–	1 (0)
Sirenidae	–	–	–	–	–	1 (0)
Order Gymnophiona	1	1 (1.0)	1 (1.0)	–	–	3 (0.33)
Dermophiidae	1	1 (1.0)	1 (1.0)	–	–	3 (0.33)
Subtotal	186	61 (0.33)	47 (0.25)	47 (0.25)	36 (0.2)	332 (0.56)
Class Reptilia						
Order Crocodylia	–	–	–	–	–	3 (0)
Alligatoridae	–	–	–	–	–	1 (0)
Crocodylidae	–	–	–	–	–	2 (0)
Order Squamata	323	166 (0.51)	133 (0.41)	130 (0.4)	104 (0.32)	577 (0.56)
Suborder Lacertilia	149	66 (0.44)	52 (0.35)	59 (0.4)	35 (0.23)	274 (0.54)
Anguidae	15	4 (0.27)	2 (0.13)	2 (0.13)	1 (0.07)	26 (0.58)
Anolidae	28	6 (0.21)	5 (0.18)	5 (0.18)	7 (0.25)	47 (0.6)
Bipedidae	–	–	–	–	–	2 (0)
Corytophanidae	3	2 (0.67)	2 (0.67)	1 (0.33)	3 (100)	5 (0.6)
Dibamidae	–	–	–	–	–	1 (0)
Diploglossidae	1	1 (1.0)	–	–	1 (1.0)	4 (0.25)
Eublepharidae	2	1 (0.5)	2 (1.0)	2 (1.0)	1 (0.5)	3 (0.67)
Gymnophthalmidae	–	–	–	–	–	1 (0)
Helodermatidae	1	1 (1.0)	1 (1.0)	1 (1.0)	–	4 (0.25)
Iguanidae	5	3 (0.6)	4 (0.8)	3 (0.6)	3 (0.6)	9 (0.56)
Phrynosomatidae	44	27 (0.61)	13 (0.3)	24 (0.55)	5 (0.11)	78 (0.56)
Phyllodactylidae	6	3 (0.5)	4 (0.67)	3 (0.5)	–	15 (0.4)
Scincidae	14	9 (0.64)	6 (0.43)	5 (0.36)	5 (0.36)	25 (0.56)
Sphaerodactylidae	2	1 (0.5)	2 (100)	–	2 (100)	3 (0.67)
Teiidae	12	7 (0.58)	7 (0.57)	10 (0.83)	3 (0.25)	25 (0.48)
Xantusidae	9	–	3 (0.33)	2 (0.22)	2 (0.22)	18 (0.5)

Biogeographic Province	SMS	TVB	Pacific	Balsas Basin	Veracruz	Total
Xenosauridae	7	1 (0.14)	1 (0.14)	1 (0.14)	2 (0.29)	8 (0.88)
Suborder Serpentes	174	100 (0.57)	81 (0.47)	71 (0.41)	69 (0.4)	303 (0.57)
Boidae	3	2 (0.67)	2 (0.67)	2 (0.67)	1 (0.33)	4 (0.75)
Colubridae	53	36 (0.68)	31 (0.58)	30 (0.57)	27 (0.51)	97 (0.55)
Dipsadidae	73	32 (0.44)	29 (0.4)	18 (0.25)	29 (0.4)	111 (0.66)
Elapidae	8	6 (0.75)	5 (0.63)	3 (0.38)	3 (0.38)	16 (0.5)
Leptotyphlopidae	6	3 (0.5)	4 (0.67)	5 (0.83)	1 (0.17)	10 (0.6)
Loxocemidae	1	1 (1.0)	1 (1.0)	1 (1.0)	1 (1.0)	1 (1.0)
Natricidae	9	7 (0.78)	2 (0.22)	5 (0.56)	2 (0.22)	20 (0.45)
Typhlopidae	–	–	–	–	–	1 (0)
Viperidae	21	13 (0.62)	7 (0.33)	7 (0.33)	5 (0.24)	43 (0.49)
Order Testudines	8	4 (0.5)	6 (0.75)	3 (0.38)	5 (0.63)	36 (0.22)
Cheloniidae	–	–	–	–	–	5 (0)
Chelydridae	1	–	–	–	1 (1.0)	1 (1.0)
Dermatemydidae	–	–	–	–	–	1 (0)
Dermochelyidae	–	–	–	–	–	1 (0)
Emydidae	–	–	–	–	–	8 (0)
Geoemydidae	2	2 (1.0)	2 (1.0)	1 (0.5)	1 (0.5)	3 (0.67)
Kinosternidae	5	2 (0.40)	4 (0.80)	2 (0.40)	3 (0.60)	15 (0.33)
Testudinidae	–	–	–	–	–	2 (0)
Subtotal	331	170 (0.51)	139 (0.42)	133 (0.4)	109 (0.33)	616 (0.54)
Total	517	231 (0.45)	186 (0.36)	180 (0.35)	145 (0.28)	948 (0.55)

The number of reptile species shared between the SMS and its neighboring provinces is greater than the number of shared amphibians. The SMS shares 51% with the Transvolcanic Belt (170 species), 42% with the Pacific Lowlands (139 species), 40% with the Balsas Basin (133 species), and 33% with the Veracruz (110 species) (Table 1, Suppl. material 2). The number of reptiles endemic to the SMS is relatively low, 41 lizards and 35 snakes, compared to amphibians. Reptiles showed a different clustering pattern from amphibians (Fig. 5B). The Central and Western subprovinces of SMS formed a pair and the Eastern subprovince of the SMS and the Balsas Basin formed a second pair. These provinces are joined with the Transvolcanic Belt to form a larger group. The Veracruz province and the Pacific Lowlands then joined this larger group.

The difference in the pattern of similarity among the subprovinces of the SMS and neighboring provinces between amphibians and reptiles warrants further investigation. Ochoa-Ochoa et al. (2014) similarly found that amphibians and reptiles in Mexico show different patterns of richness and endemism among regions. Possible explanations include differences in environmental tolerances of amphibians and reptiles. For example, due to their environmental requirements of humidity, temperature, and water quality for reproduction and survival, amphibians may be more limited in their distributions than reptiles (Buckley and Jetz 2007; Titon and Gomes 2015). Reptiles can typically tolerate a wider range of environmental conditions, and have greater mobility, contributing to a broader and less restricted distribution compared to amphibians (Pianka and Vitt 2003). In addition, the rate of diversification and extinction in each province may differ due to the specific characteristics of that province being more conducive to isolation of populations, either physically or ecologically (e.g., Rovito 2017; Gray et al. 2019; Cisneros-Bernal et al. 2022; Gutiérrez-Rodríguez et al. 2022; Butler et al. 2023).



Figure 4. Photos of some of the snake species endemic to the Sierra Madre del Sur **A, B** *Geophis laticollaris*, Malinaltepec, Guerrero **C, D** *Rhadinaea myersi*, Malinaltepec, Guerrero **E, F** *Mixcoatlus barbouri*, Malinaltepec, Guerrero **G, H** *Ophryacus sphenophrys*, Candelaria Loxica, Oaxaca. All photos by Eric Centenero-Alcalá.

The cluster analyses also suggest that the SMS is not homogeneous with respect to its herpetofauna given that its three subprovinces do not cluster together, although the Western and Central subprovinces do. This is especially true for the amphibians. For amphibians, this pattern may reflect the high level of

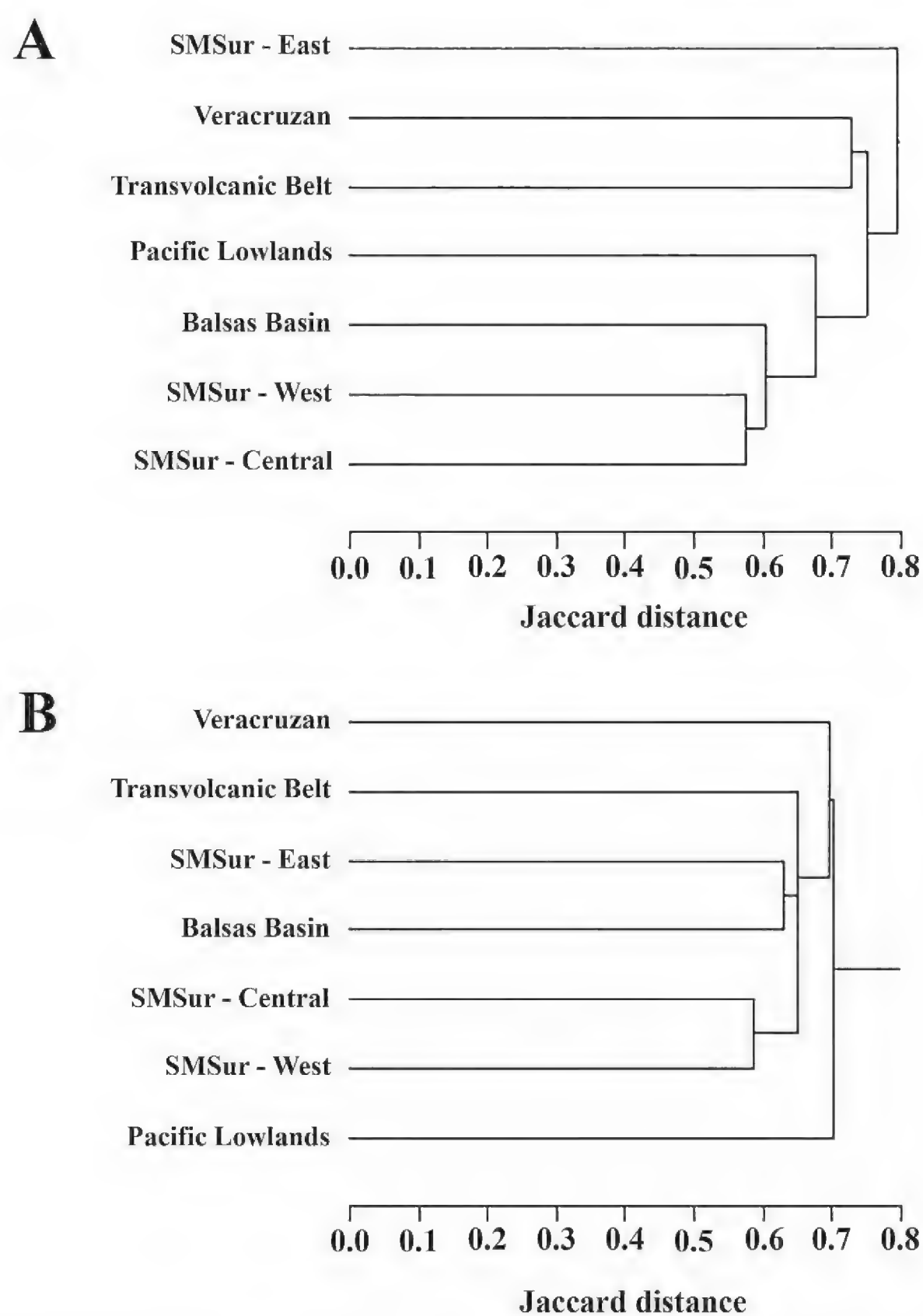


Figure 5. Cluster trees for **A** amphibians and **B** reptiles of the subprovinces of the Sierra Madre del Sur and its neighboring biogeographic provinces.

endemism, with > 50% of the species endemic to the SMS. In particular, most of the species endemic to the SMS are endemic to the Eastern subprovince, which may also explain why the Eastern subprovince is relatively unique and clusters outside the other subprovinces and provinces. For reptiles, the Eastern province is not as distinct, but it does cluster more closely to the Balsas Basin and is generally more similar to the other subprovinces of the SMS than in the amphibians. This pattern does not appear to support the SMS as a biogeographic province, at least not with the subprovince division used here, and not with respect to the amphibians and reptiles (see Luna-Vega et al. 1999; Santiago-Alvarado et al. 2016).

Conservation status

One hundred and fourteen (26.1% = 114/436 evaluated) of the 517 native species of amphibians and reptiles that inhabit the Sierra Madre del Sur (SMS) are included in the IUCN Red List in some category of conservation concern (i.e., Vulnerable, Endangered, or Critically Endangered); 60 (11.6% = 60/517 evaluated)

are listed in the risk categories of threatened (A) or in danger of extinction (P) by Secretaría del Medio Ambiente y Recursos Naturales de México (SEMARNAT), (excluding NL [Not Listed] and Pr [Subject to special protection], this last category is comparable to the LC category of the IUCN), and 255 (53.6% = 255/476 evaluated) are considered high-risk by the Environmental Vulnerability Score (EVS) (Table 2, Suppl. material 1, Fig. 6). Ninety-six amphibian species, equivalent to 55.2% (96/174 evaluated), are included in the IUCN Red List: 15 Vulnerable, 44 Endangered, and 37 Critically Endangered. According to the IUCN Red List (IUCN 2024), all of the listed amphibian species (96) are endemic to Mexico, 78 are endemic to the SMS, and 69 have a decreasing population trend. Three species are cataloged as Data Deficient (DD), all three are endemic to the SMS, specifically to the Eastern subprovince: *Charadrahyla tecuani*, *Sarcohyala miahuatlanensis*, and *Thorius hankeni*, and 12 have not been evaluated, nine are endemic to Mexico and eight of these to the SMS (Table 2, Suppl. material 1). Eight of the nine endemic species that have not been evaluated were recently described: *Craugastor bitonium*, *Craugastor candelariensis*, *Craugastor polaclavus*, *Craugastor portilloensis*, *Eleutherodactylus jamesdixoni*, *Eleutherodactylus maculabialis*, *Eleutherodactylus sentinelus*, and *Bolitoglossa coaxtlahuacana*. The other species that is endemic to Mexico that has not been evaluated by the IUCN was recently recognized as a species: *Eleutherodactylus petersi*, and was previously considered as a subspecies (*E. nitidus petersi*) (Grünwald et al. 2021a). The other three species have a broad distribution and have undergone taxonomic changes that make their evaluation difficult: *Rhinella horribilis*, *Hyalinobatrachium viridissimum*, and *Trachycephalus vermiculatus*. Eighteen species of amphibians (9.7% = 18/186 evaluated) are categorized as threatened (A) or in danger of extinction (P) by the Mexican government (SEMARNAT 2019); and 96 species (58.9% = 96/163 evaluated) are considered high-risk by EVS (Table 2, Fig. 6).

The highest proportion of species with conservation concern status occurs in the Eastern subprovince with 90 species (93.8% = 90/96) (Suppl. material 1). The other two subprovinces have only three species with conservation concern status (3.1% = 3/96) (Suppl. material 1). Seventy-four of the 90 species with conservation concern status that inhabit the Eastern subprovince are endemic to this subprovince, one bufonid, three craugastors, 25 hylids, one frog, and 44 plethodontids (Suppl. material 1). The other 16 species are endemic to Mexico, but are distributed in more than one biogeographic province: two bufonids, one craugastor, ten hylids, and three plethodontids (Suppl. material 1). The species with conservation concern status of the Western subprovince are: *Eleutherodactylus manantlanensis*, *Eleutherodactylus grunwaldi*, and *Eleutherodactylus jaliscoensis*. The species with conservation concern status in the Central subprovince are: *Incilius pisinnus*, *Eleutherodactylus nietoi*, and *Eleutherodactylus rufescens*.

According to the IUCN (2024), the 90 species of amphibians with conservation concern status that inhabit the Eastern subprovince are mainly threatened by the accelerated loss of their habitat and the presence of the pathogenic chytrid fungus *Batrachochytrium dendrobatidis* (*Bd*) and *B. salamandrivorans* (*Bsal*), which attack anurans and salamanders respectively. Although the presence of *Bsal* has not been confirmed in the Americas the threat of infection, and population declines in salamanders, is thought to be highly likely and detrimental to the majority of native species, should the fungus arrive in Mexico (Basanta et al. 2019; IUCN 2024). Furthermore, species such as *Dryophytes arboricola* have

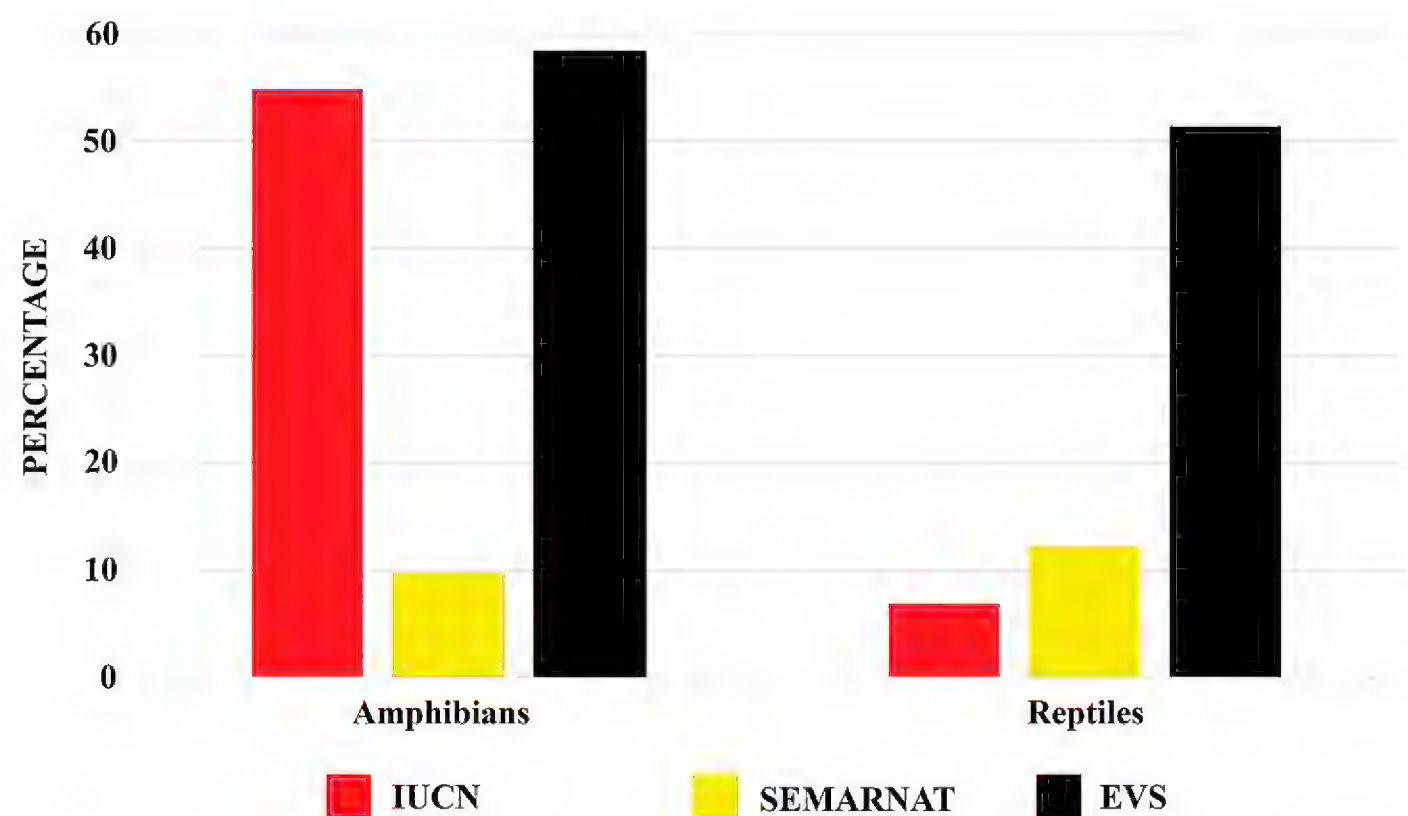


Figure 6. Percentage of amphibian and reptile species with conservation concern status (IUCN 2024), categorized as threatened (A) or in danger of extinction (P) by the Mexican government (SEMARNAT 2019), or deemed to have a high environmental vulnerability score (EVS), for the Sierra Madre del Sur biogeographic province of Mexico.

been found in the pet trade without knowing the impact that their populations are suffering through their commercialization; and the only aquatic plethodontid species in Mesoamerica, *Pseudoeurycea aquatica*, faces problems due to the introduction of Trout (*Oncorhynchus* spp.) to the streams in which it lives (IUCN 2024). Most of these species have a distribution limited to cloud, rainforest, or pine-oak forests. The cloud forest is one of the most threatened types of habitats in Mexico, characterized by a large loss of vegetation cover and a high incidence of economic activities that modify its structure and species composition (Ochoa-Ochoa et al. 2017). This type of habitat hosts the genus of Mexican Pigmy Salamanders (*Thorius*) endemic to Mexico, which is made up of 29 species; 20 of them inhabit the Eastern subprovince and 19 are endemic to this subprovince. Likewise, anuran species such as *Craugastor spatulatus*, *Charadrahyla altipotens*, *Ecnomiohyla echinata*, *Megastomatohyla pellita*, *Sarcohyla cyanomma*, and *Sarcohyla sabrina*, among others, occupy this type of habitat that is rapidly being lost in Mexico. In addition, there are ten species in the Eastern subprovince that the IUCN (2024) reports as possibly extinct: *Ecnomiohyla echinata*, *Sarcohyla calvicollina*, *Sarcohyla cyanomma*, *Sarcohyla psarosema*, *Sarcohyla sabrina*, *Sarcohyla siopela*, *Pseudoeurycea anitae*, *Pseudoeurycea teotepec*, *Pseudoeurycea unguidentis*, and *Thorius longicaudus*, all of which face the problem of the accelerated loss of its habitat and the potential threat of emerging diseases caused by pathogenic chytrid fungus.

The three species of conservation concern that inhabit the Western subprovince are endemic to it, and all three face accelerated habitat loss as the main threat to their existence: *Eleutherodactylus manantlanensis* inhabits oak and pine forests that are being reforested with native and non-native pine species; the forests occupied by *Eleutherodactylus grunwaldi* are being strongly affected by iron mining; and *Eleutherodactylus jaliscoensis* is losing its habitat through deforestation (IUCN 2024). Likewise, the three species of conservation concern that inhabit the Central subprovince face the accelerated loss of their habitat

as the main threat. One of them is endemic to this subprovince: *Eleutherodactylus nietoi*, its habitat represented by oak and pine forests is being reforested with native and non-native pine species; the other two species are not endemic to this subprovince and are losing their habitat through extensive agriculture and livestock (IUCN 2024). The combination of the very limited distribution of these species, accelerated loss of habitat, susceptibility to emerging diseases, introduction of non-native species, and commercialization of some of them, is lethal for the existence of the amphibians of this biogeographic province. With the exception of emerging diseases, other threats can be reduced by increasing the number of protected areas in the province, an increase that must be accompanied by policies to improve the living conditions of the human population to prevent the predation of the natural resources in these protected areas.

For reptiles in the SMS a much lower proportion of species are of conservation concern compared to the amphibians. Only 6.9% (18/262 evaluated) are included in some category of conservation concern in the IUCN Red List, 12.7% (42/331 evaluated) are categorized as threatened (A) or in danger of extinction (P) by the Mexican government, and 51.1% (159/311 evaluated) are considered at high risk by EVS (Fig. 6). The 18 reptile species included in the IUCN Red List with some category of conservation concern include ten Vulnerable, seven Endangered, and one Critically Endangered. Most of these have a decreasing population according to the IUCN Red List (IUCN 2024), and all but one (*Chelydra rossignonii*) is endemic to Mexico, and seven are endemic to the SMS. The Eastern subprovince hosts 17 of the 18 species in a category of conservation concern. The other species of conservation concern (*Crotalus pusillus*) inhabits the Central subprovince. The main threat to these 18 species is the rapid loss of their habitat due to deforestation for conversion to agriculture, excessive logging, intentional fires, urbanization, and overgrazing. Three species of lizards (*Abronia graminea*, *Abronia mixteca*, and *Xenosaurus grandis*) face illegal collection due to the pet trade. One iguana *Ctenosaura oaxacana* and one turtle *Chelydra rossignonii*, are harvested for human consumption (IUCN 2024).

According to these numbers, the reptiles of the SMS are of lower conservation concern compared to the amphibians, however, taking into account that 69 species have not been evaluated by the IUCN Red List, and another 49 have the status of data deficient, the actual conservation status of 118 species is unknown. It is possible that this low number of species that are of conservation concern is misleading, especially since 22 of the species with data deficient status and 33 that have not been evaluated have a restricted distribution (in some cases limited to the type locality) and are endemic to the SMS, and another 23 (13 data deficient and 10 not evaluated) are distributed only in the SMS and another biogeographic province. Therefore, as with the amphibians, the most prudent approach is to protect the reptile species of the SMS by increasing the number of areas protected by federal and state governments, especially in the Eastern subprovince. In addition, protections driven by local communities should be promoted since this approach has been shown to be more effective than federal or state protections that in most cases are just on paper and not enforced in the field (Bray 2020). Such community-based actions are born from the concern of those directly affected, sometimes with the help of non-governmental organizations, and focus on the benefit of sustainable development to rural populations.

Table 2. Summary of native species present in the Sierra Madre del Sur (SMS) by Family, Order or Suborder, and Class. Status summary indicates the number of species found in each IUCN conservation status in the order DD (Data Deficient); LC (Least Concern); NT (Near Threatened); V (Vulnerable); E (Endangered); CR (Critically Endangered) (in some cases, species have not been assigned a status by the IUCN and therefore these may not add up to the total number of species in a taxon). Mean EVS is the mean Environmental Vulnerability Score, scores ≥ 14 are considered high vulnerability (Wilson et al. 2013a, 2013b) and category of risk in Mexico according to SEMARNAT (2019) in the order: NL (not listed); Pr (subject to special protection); A (threatened); P (in danger of extinction).

Scientific Name	Genera	Species	IUCN	x̄ EVS	SEMARNAT
			DD, LC, NT, VU, EN, CR		NL, Pr, A, P
Class Amphibia					
Order Anura	28	131	2,63,6,13,23,13	12.2	89,33,8,1
Bufonidae	3	11	0,6,0,1,3,0	10.5	9,2,0,0
Centrolenidae	1	1	0,0,0,0,0,0	10	1,0,0,0
Craugastoridae	1	20	0,11,1,1,3,0	14.2	14,6,0,0
Eleutherodactylidae	1	19	0,10,0,1,3,1	14.7	15,4,0,0
Hylidae	17	64	2,21,5,10,13,12	12.3	42,15,7,0
Leptodactylidae	1	2	0,2,0,0,0,0	5.5	2,0,0,0
Microhylidae	1	2	0,2,0,0,0,0	5.5	1,1,0,0
Ranidae	1	10	0,9,0,0,1,0	10.7	4,4,1,1
Rhinophrynidae	1	1	0,1,0,0,0,0	8	0,1,0,0
Scaphiopodidae	1	1	0,1,0,0,0,0	6	1,0,0,0
Order Caudata	5	54	1,3,2,2,21,23	17	36,9,9,0
Ambystomatidae	1	1	0,1,0,0,0,0	10	0,1,0,0
Plethodontidae	4	53	1,2,2,2,21,24	17.1	36,8,9,0
Order Gymnophiona	1	1	0,1,0,0,0,0	12	0,1,0,0
Dermophiidae	1	1	0,1,0,0,0,0	12	0,1,0,0
Subtotal	34	186	3,67,8,15,44,37	13.7	125,43,17,1
Class Reptilia					
Order Squamata	84	323	48,189,4,9,7,1	12.8	173,109,41,0
Suborder Lacertilia	24	149	18,88,1,4,3,1	13.3	82,46,21,0
Anguidae	4	15	1,3,0,2,3,0	14.8	4,7,4,0
Anolidae	1	28	4,16,1,0,0,0	14	18,7,3,0
Corytophanidae	2	3	0,3,0,0,0,0	8	1,2,0,0
Diploglossidae	1	1	0,1,0,0,0,0	14	0,1,0,0
Eublepharidae	1	2	0,1,0,0,0,0	9	1,1,0,0
Helodermatidae	1	1	0,1,0,0,0,0	11	0,1,0,0
Iguanidae	2	5	0,4,0,0,0,1	13.2	0,2,3,0
Phrynosomatidae	3	44	3,33,0,1,0,0	13.1	31,8,5,0
Phyllodactylidae	1	6	0,5,0,0,0,0	14.8	2,3,1,0
Scincidae	3	14	3,6,0,0,0,0	12.8	9,4,1,0
Sphaerodactylidae	1	2	0,1,0,0,0,0	11	1,1,0,0
Teiidae	2	12	0,10,0,0,0,0	12.3	6,6,0,0
Xantusidae	1	9	6,2,0,0,0,0	13.3	3,2,4,0
Xenosauridae	1	7	1,2,0,1,0,0	13.3	6,1,0,0
Suborder Serpentes	61	174	30,101,3,5,4,0	12.3	91,63,20,0
Boidae	2	3	0,1,0,1,0,0	11.7	2,1,0,0
Colubridae	21	53	6,39,2,0,1,0	11.5	33,11,9,0
Dipsadidae	24	73	21,40,0,2,0,0	12.3	35,37,1,0
Elapidae	1	8	1,6,0,1,0,0	13.5	0,8,0,0
Leptotyphlopidae	2	6	0,2,0,0,0,0	8.5	6,0,0,0
Loxocemidae	1	1	0,1,0,0,0,0	10	0,1,0,0
Natricidae	2	9	0,7,0,0,0,0	12.7	5,0,4,0
Viperidae	8	21	2,5,1,1,3,0	15.2	10,5,6,0
Order Testudines	4	8	1,1,1,1,0,0	12.3	1,6,1,0
Chelydridae	1	1	0,0,0,1,0,0	17	1,0,0,0
Geoemydidae	1	2	0,0,1,0,0,0	11	0,1,1,0
Kinosternidae	2	5	1,1,0,0,0,0	11.8	0,5,0,0
Subtotal	89	331	49,190,5,10,7,1	12.8	174,115,42,0
Total	123	517	52,257,13,25,51,38	13.1	300,157,59,1

Conclusions

In conclusion, our summary of the species of amphibians and reptiles in the SMS province and its subprovinces highlights the diversity and conservation challenges of the herpetofauna in this unique biogeographic province. The geographic complexity of the Sierra Madre del Sur, characterized by considerable altitudinal gradients that occur over short distances, provides a great variety of spaces that have resulted in high biodiversity, including the greatest diversity of amphibians and reptiles for a biogeographic province of Mexico. This high diversity of amphibians and reptiles is accompanied by an equally high proportion of endemic species, so the species of amphibians and reptiles that inhabit the Sierra Madre del Sur will have a delicate or fragile state of conservation that will be reflected in a high percentage of species of these two classes of terrestrial vertebrates included in the IUCN Red List with status of conservation concern. However, our analysis of the similarities of the SMS province and its subprovinces with neighboring biogeographic provinces indicates that the herpetofauna of the SMS province should not be treated as a single biogeographic entity and therefore may not warrant a single conservation approach or strategy. In addition, more than a quarter of the evaluated species of amphibians and reptiles are considered Vulnerable, Endangered, or Critically Endangered by the IUCN Red List suggesting the SMS is also home to a high number of threatened species, which is likely an underestimate given the high number of “data deficient” or “not evaluated” species. Our examination of the herpetofauna of the SMS thus makes it clear that it is a critical component of the diversity of Mexican amphibian and reptiles and deserves increased research and conservation efforts. In particular, the Eastern subprovince has a unique herpetofauna, especially its amphibian species. This deserves special consideration from a conservation standpoint given the high level of species endemic to this subprovince.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

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Author contributions

Conceptualization: GRS, JAL-E. Data curation: JAL-E, GRS. Formal analysis: GRS, JAL-E. Investigation: JAL-E, GRS. Methodology: JAL-E, GRS. Writing - original draft: GRS, JAL-E. Writing - review and editing: JAL-E, GRS.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Appendix 1

Literature sources used to create the species lists of amphibians and reptiles of the Sierra Madre del Sur used in this publication

Ahumada-Carrillo et al. (2020); Alvarado-Díaz et al. (2013); Blancas-Hernández et al. (2019); Bryson et al. (2021); Campbell et al. (2016, 2018); Campillo-García et al. (2021); Canseco-Márquez et al. (2017a, 2017b); Carbajal-Márquez et al. (2020); Cavazos-Camacho and Ahumada-Carrillo (2020); Caviedes-Solis and Nieto-Montes de Oca (2018); Cox et al. (2018); Cruz-Sáenz et al. (2017); De la Torres-Loranca et al. (2020); Everson et al. (2021); Fernández-Badillo et al. (2020); Flores-Villela et al. (2022); García-Padilla et al. (2019); García-Vázquez et al. (2018, 2021); Gray et al. (2016); Grünwald et al. (2018, 2019, 2021a, 2021b); Hernandez et al. (2022); Hernández-Austria et al. (2024); Hillis et al. (1983); Horowitz (1955); Jameson et al. (2022); Kaplan et al. (2020); Köhler et al. (2019); Lara-Tufiño and Nieto-Montes de Oca (2021); Lavin et al. (2014); Lemos-Espinal and Smith (2023); Lemos-Espinal et al. (2020); Mata-Silva et al. (2015, 2019, 2021); McCranie and Köhler (2004); McCranie et al. (2020); Mendoza-Hernández and Roth-Monzón (2017); Montanucci (1979); Montaña-Ruvalcaba et al. (2020); Nieto-Montes de Oca et al. (2022); O’Connell and Smith (2018); Palacios-Aguilar and Flores-Villela (2018, 2020); Palacios-Aguilar and Santos-Bibiano (2020); Palacios-Aguilar et al. (2018); Parra-Olea et al. (2016); Pazos-Nava et al. (2019); Pérez-Ramos and Saldaña-de La Riva (2008); Platz (1991); Ramírez-Reyes and Flores-Villela (2018); Ramírez-Reyes et al. (2017); Reyes-Velasco et al. (2020a, 2020b); Sánchez-García et al. (2020); Schätti et al. (2020); Smith and Lemos-Espinal (2022); Streicher et al. (2014); Tepos-Ramírez et al. (2021); Torres-Hernández et al. (2021); Wallach (2016); Webb (2001); Woolrich-Piña et al. (2017); Zaldivar-Riverón et al. (2004).

Supplementary material 1

Amphibians and reptiles of the Sierra Madre del Sur

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Supplementary material 2

The species of amphibians and reptiles of the SMS that are shared with its four neighboring biogeographic provinces

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